HEAVY DARK MATTER IN THE GALACTIC CENTER

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- Gamma-Ray Measurements
  - -ACTs: HESS, Whipple, Cangaroo-II
  - -Satellites: EGRET and the Future Role of GLAST
- Dark Matter?
  - -Gamma-Ray Spectrum and Flux
  - -Characteristics Required to Accommodate HESS Data
- Messenger Dark Matter
  - -Messenger Sector, Gauge Mediated SUSY Dark Matter Model
  - -Plausible and Attractive Source of HESS Signal

Based on hep-ph/0412048, PLB, with J. March-Russell and
astro-ph/0404205, JCAP, with I. Perez, J. Silk, F. Ferrer and S. Sarkar

Gamma-Rays From Dark Matter Annihilation: Spectral Features

- Line Emission

  -No tree level photon final states for typical DM candidates

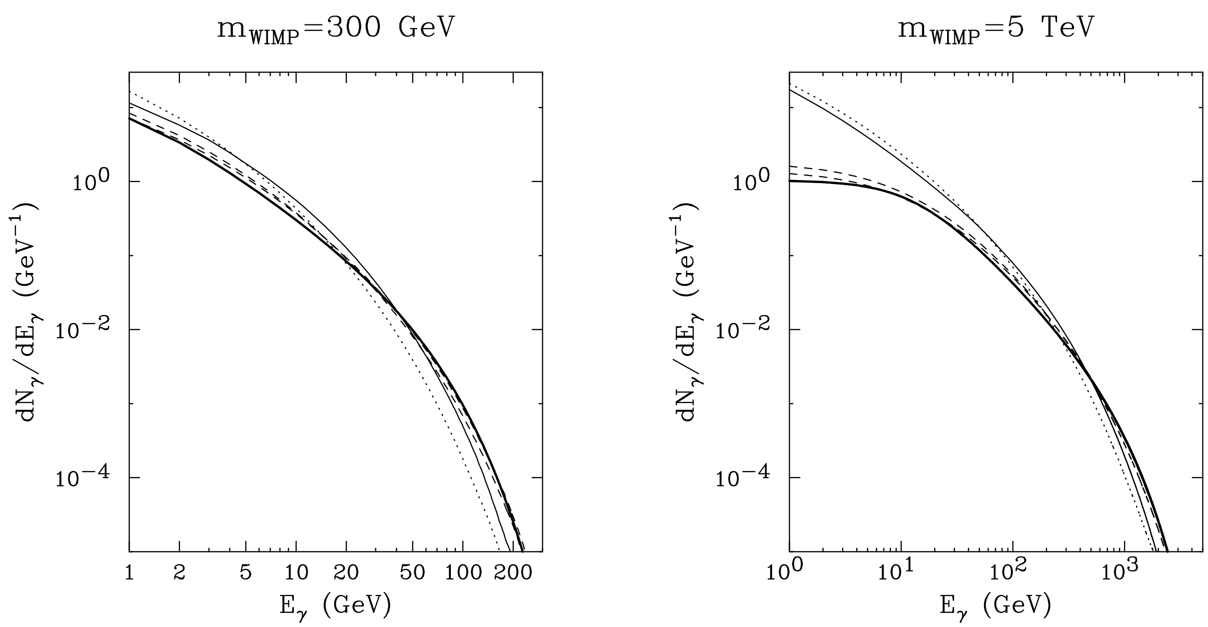
  -Loop diagrams to $\gamma\gamma$, γZ, γH

  -Smaller cross section, but distinctive features

- Continuum Emission

  -Annihilations to gauge bosons, quarks, leptons, etc. contribute

  -Typical energies much lower than WIMP mass



GAMMA-RAY SPECTRUM: BEFORE HESS

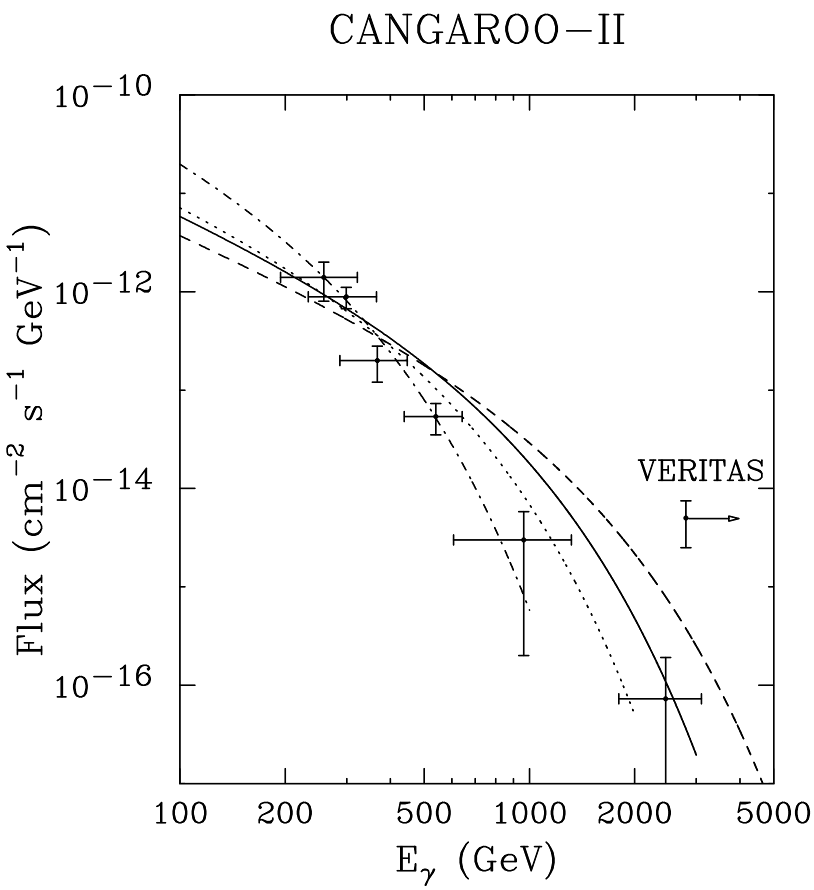
- CANGAROO-II Observation

  -Spectrum consistent with 1-3 TeV annihilating particle

- Whipple Observation

  -Substantial flux *above* 2.8 TeV

  -Difficult to reconcile with CANGAROO-II



(Hooper, *et al.*, JCAP, astro-ph/0404205)

AND THEN THERE WAS HESS...

- The HESS Telescope

  -Array of 4 ACTs

  -Southern Hemisphere Location (Namibia)

  -Superior Spectral *and* Angular Resolution

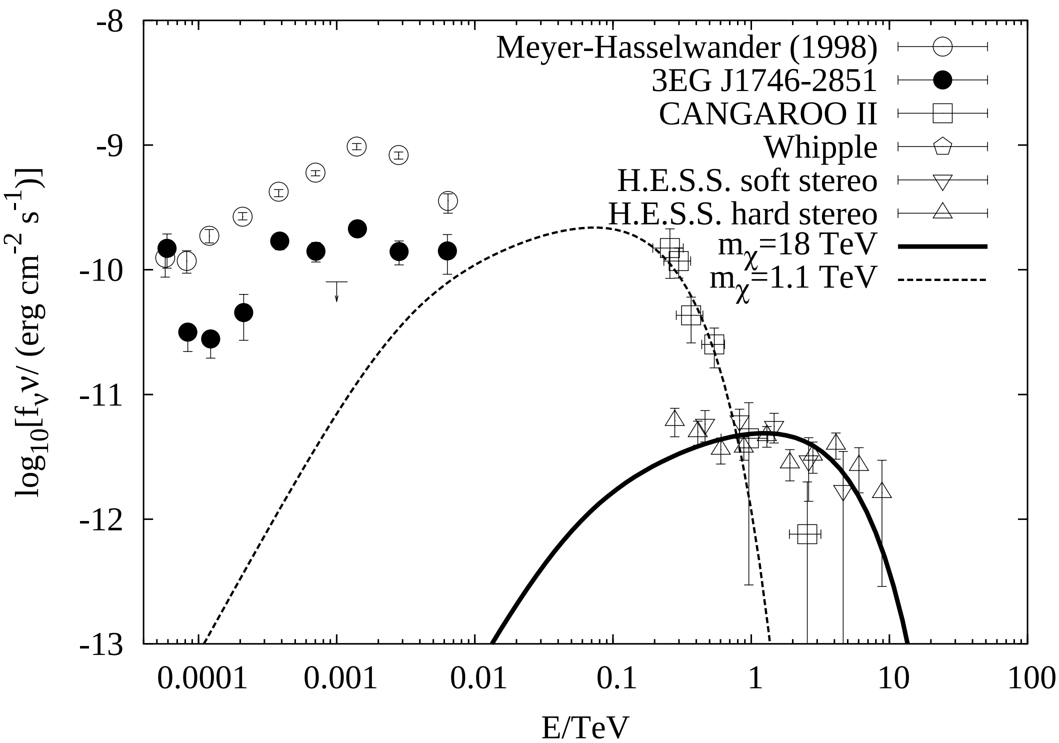
GAMMA-RAY SPECTRUM: AFTER HESS

- HESS Observation

  -Spectrum Extending to ~ 10 TeV

  -Very different from Cangaroo-II spectrum

  -Roughly consistent with Whipple



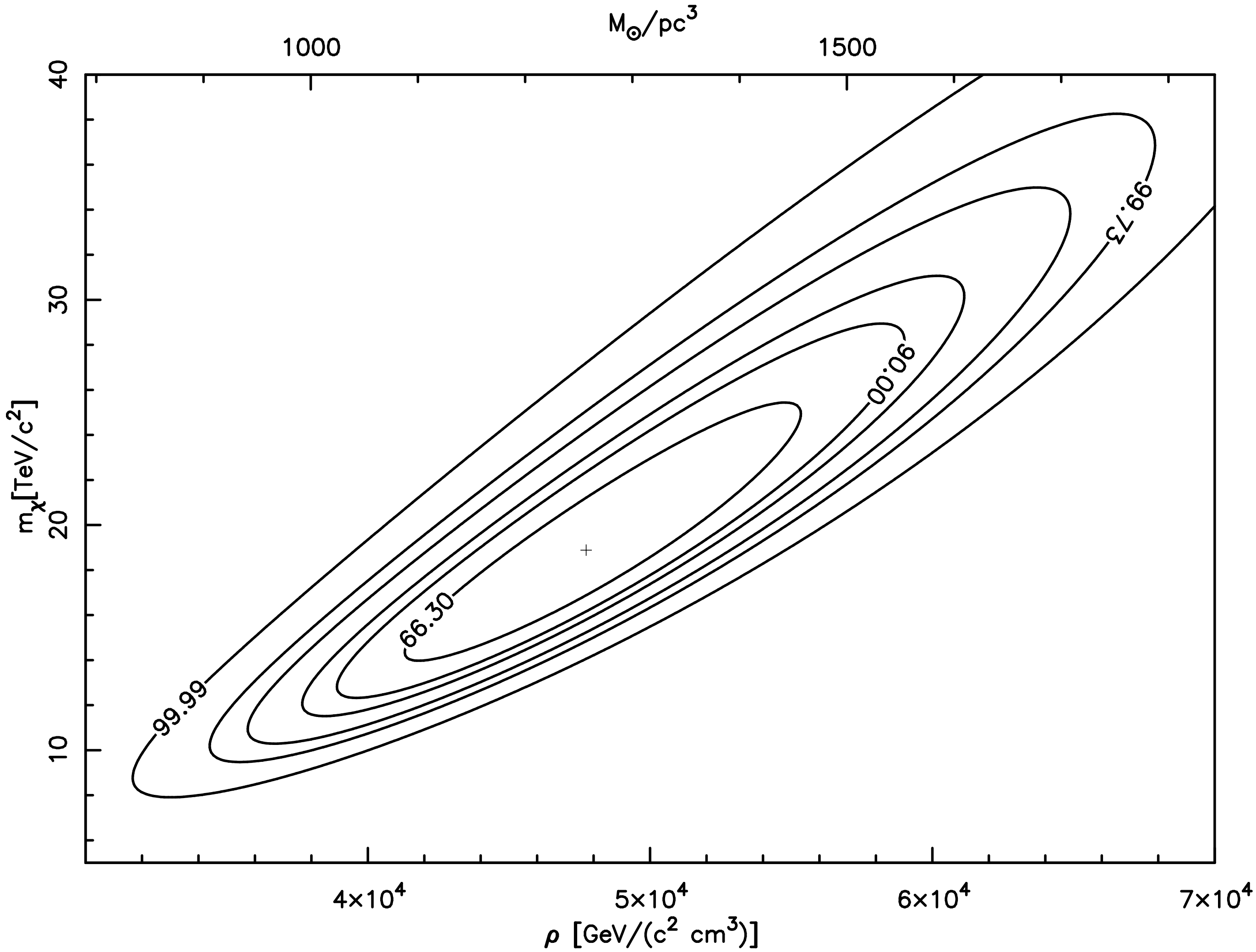
(D. Horns, astro-ph/0408192)

GAMMA-RAY SPECTRUM: AFTER HESS

- ► Dark Matter Characteristics

  -Requires 10-40 TeV mass

  -Well outside of range generally favored



(D. Horns, astro-ph/0408192)

Can A Neutralino Be As Heavy As 10-40 TeV?

– Very heavy neutralinos tend to overclose Universe

– Largest annihilation cross sections (lowest relic density) are found for models in which the lightest neutralino is Wino-like or Higgsino-like

– $\Omega h^2 \sim 0.1$ for ~ 1 TeV Wino, or ~ 3 TeV Higgsino

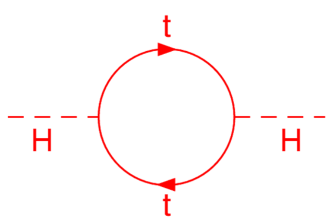
– Larger masses are only possible if coannihilations are carefully arranged

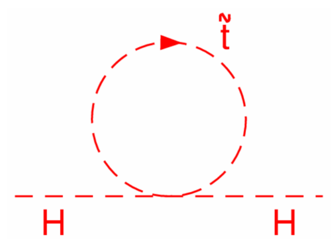
Can A Neutralino Be As Heavy As 10-40 TeV?

– Electroweak precision measurement infer the presence of a light higgs boson (not much above EW scale)

– Large contributions to the higgs mass come from particle loops

$$\Delta m_H^2 = -\frac{\lambda_t^2}{8\pi^2}\Lambda^2 \qquad\qquad \Delta m_H^2 = +\frac{\lambda_t^2}{8\pi^2}\Lambda^2$$





– In unbroken SUSY, fermion and boson contributions cancel

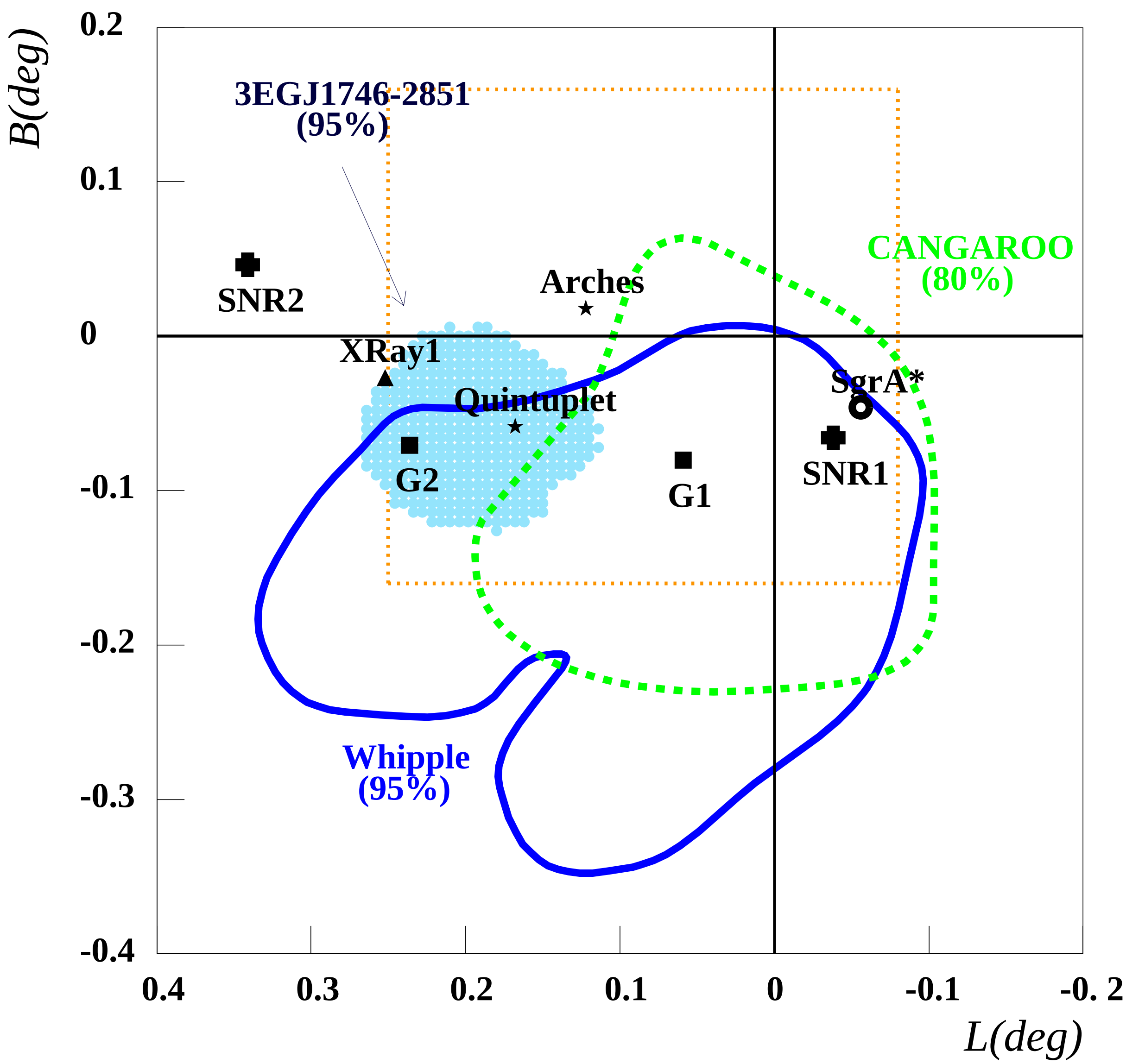
– If $m_{\rm SUSY} \gg m_{\rm H}$, precise fine tuning required

– $m_{\rm SUSY} \lesssim$ TeV strongly preferred

Location, Location, Location

- Before HESS

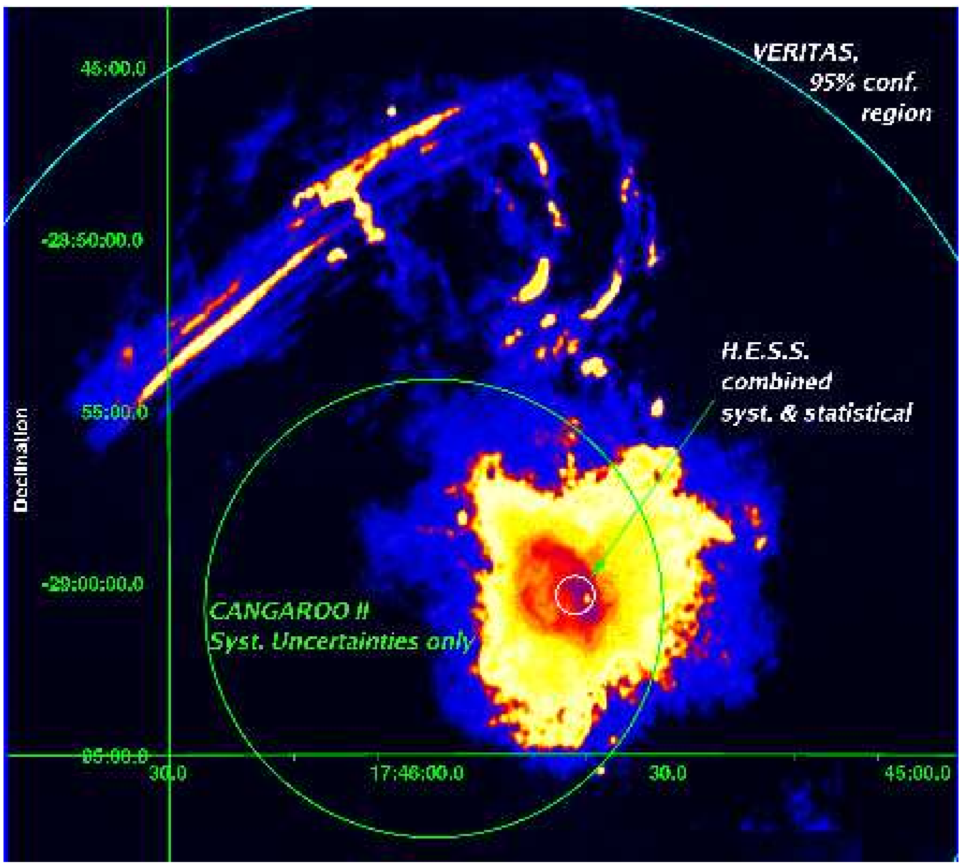
  -Ambiguity in Source Location(s)



(Hooper, *et al.*, JCAP, astro-ph/0404205)

Location, Location, Location

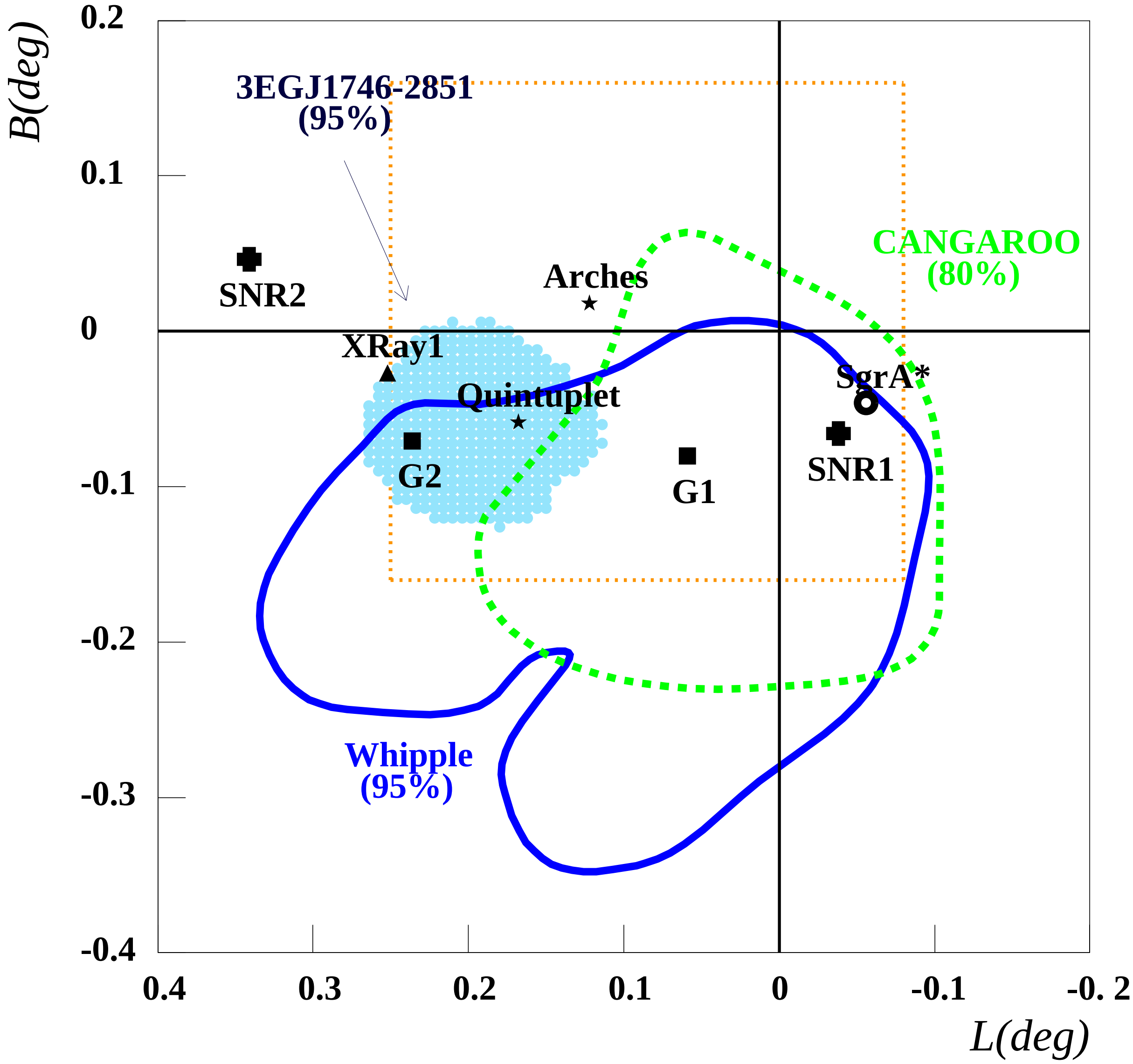
- After HESS
  -Precise angular resolution
  -Leaves only Sgr A* and nearby SNR as likely sources



(D. Horns, astro-ph/0408192)

THE EGRET SOURCE

- Does EGRET see the same source?



THE EGRET ANALYSIS

- EGRET: The Energetic Gamma Ray Experiment Telescope

  -Launched on the Compton Gamma Ray Observatory in 1991

  -Sensitive To gamma rays between 30 MeV and 30 GeV

  -Accumulated an exposure of $\simeq .2 \times 10^{10}\,\mathrm{cm}^2\,\mathrm{sec}$ of the galactic center region

- Galactic Center Source?

  -Original EGRET analysis: single point spread function and 0.5° bins

  -$\longrightarrow$ Flux found of $\sim 10^{-7}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$ above 1 GeV, consistent with GC

  -Dingus/Hooper analysis: energy dependent point spread function and unbinned technique

  -$\longrightarrow$ Source of flux 0.2° off-center, excluded from GC beyond 99.9%

  -$\longrightarrow$ Limit from GC of $10^{-7} - 10^{-8}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$

  -Consistent with HESS

(Hooper and Dingus, PRD, astro-ph/0210617)

GAMMA-RAYS FROM DARK MATTER ANNIHILATION: FLUX MAGNITUDE

- Gamma-Ray Flux

  $\Phi_\gamma(\psi, E_\gamma) = \langle\sigma v\rangle \frac{\mathrm{dN_\gamma}}{\mathrm{dE_\gamma}} \frac{1}{4\pi M_X^2} \int_{\mathrm{los}} \mathrm{dl}(\psi)\, \rho^2(\mathrm{r})$

  Break down Into 2 factors:

  1) halo characteristics

  2) particle physics

- Halo Factor

  $J(\psi) = \frac{1}{8.5\,\mathrm{kpc}} \left(\frac{1}{0.3\,\mathrm{GeV/cm^3}}\right)^2 \int_{\mathrm{los}} \mathrm{dl}(\psi)\, \rho^2(\mathrm{l})$

  -Value of $J(\Delta\Omega)$ highly uncertain

Halo Models

- Cuspy Halo Models

  - N-body simulations favor cusped halo models, $\rho \propto 1/r^{\gamma}$, $\gamma \sim 1.2$

  -Includes Navarro, Frenk, White (NFW), and Moore *et.al.* profiles

  -$J(5 \times 10^{-5}\,\mathrm{sr}) \sim 10^4$ to 10^6

  -With 10 arcminute resolution, appears as point source

- Core Halo Models

  -Some observations favor models with flat cores, $\gamma \sim 0$

  -Not dense enough to observe dark matter annihilation

  -Produces extended annihilation signal

- Other Effects

  -Adiabatic compression $\rightarrow$ $J(5 \times 10^{-5}\,\mathrm{sr}) \sim 10^6$ to 10^8

  -Adiabatic accretion onto SMBH $\rightarrow$ density spike, $\gamma \simeq 2.4$

A Signal of Dark Matter?

- Dark Matter Requires:

  1) Very heavy particle ($\sim$10-40 TeV)

  AND

  2) Extremely dense inner halo (spikes, adiabatic compression, etc)

- Astrophysical Alternatives (Examples)

  1) Acceleration associated with SMBH (several possibilities)

  2) Nearby supernova remnant too near to rule out

(See: Aharonian and Neronov, astro-ph/0408303; Atoyan and Dermer, astro-ph/0410243)

Heavy Dark Matter?

- Electroweak Scale (10 GeV - a few TeV)
  Neutralinos (or other superpartners), Kaluza-Klein Dark Matter, etc.
  Numerous examples associated with electroweak symmetry breaking or solutions to the hierarchy problem
- Light Dark Matter
  Sub-eV masses: axinos
  MeV masses: Source of 511 keV emission from galactic bulge?
- Superheavy Dark Matter
  GUT scale? Inflationary scale? Planck scale?
  Source of ultra-high energy cosmic rays?

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  Source of ultra-high energy cosmic rays?
- 10-50 TeV Range?
  Little attention in the literature
  Perhaps due to difficulty in detecting such a candidate?

MESSENGER DARK MATTER

- Gauge Mediated Supersymmetry Breaking
  -Supersymmetry is broken in $\sim$100 TeV sector
  -Messengers communicate SUSY breaking through gauge couplings
  -LSP is a light gravitino (1-10 eV)
- Messenger Particles
  -Lightest messenger particle is naturally stable
  -MultiTeV scalar neutrino natural dark matter candidate

Hooper and J. March-Russell, PLB, hep-ph/0412048,
Dimopoulos, Giudice and Pomarol, PLB, hep-ph/9607225,
Han and Hempfling, PLB, hep-ph/9708264

Messenger Dark Matter

- Messenger Particles

  -Phenomenological problems present in minimal SUSY model

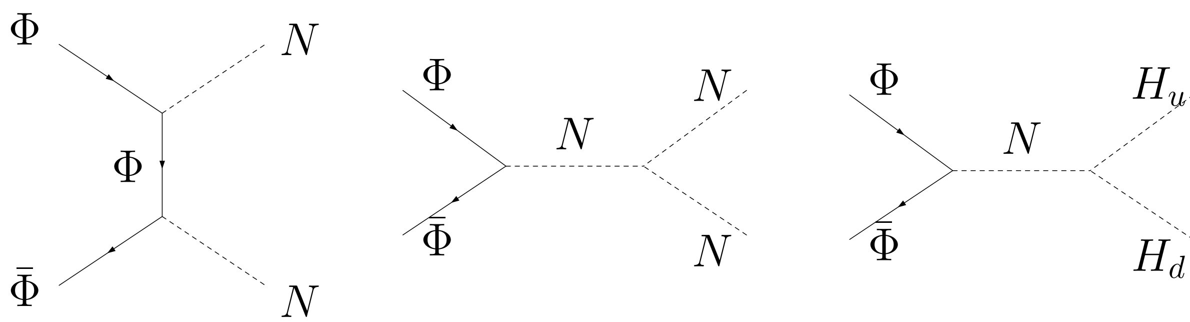
  -Consider model with additional Higgs singlet (NMSSM inspired)

- Messenger Annihilations

  -Potential includes the terms:

  $V = (4\xi_S\xi_N - 2\xi_N\eta_N)SN\bar{\Phi}\Phi + 2\eta_N kSN^3 - 2\eta_N\lambda_N NSH_uH_d + ...$

  -Leads to the annihilation diagrams:



  -These diagrams are enhanced due to large $\langle S\rangle \sim 100$ TeV

  -Yields observed dark matter density for $m_{\phi^0} \simeq 7$ to 30 TeV

Hooper and J. March-Russell, PLB, hep-ph/0412048

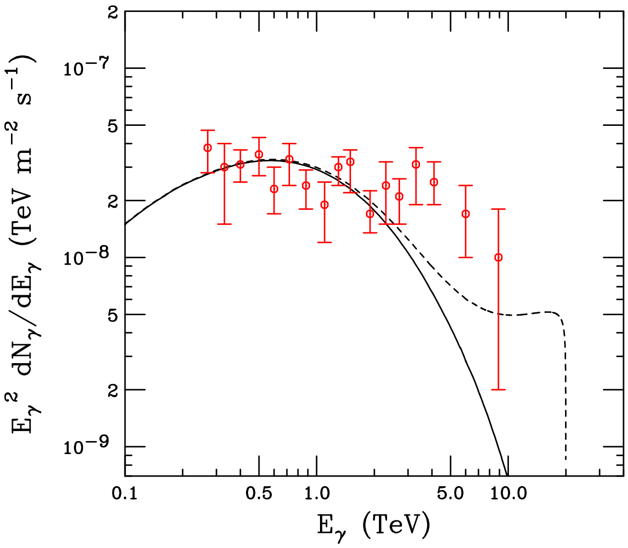
Han, Marfatia and Zhang, PRD, hep-ph/9906508

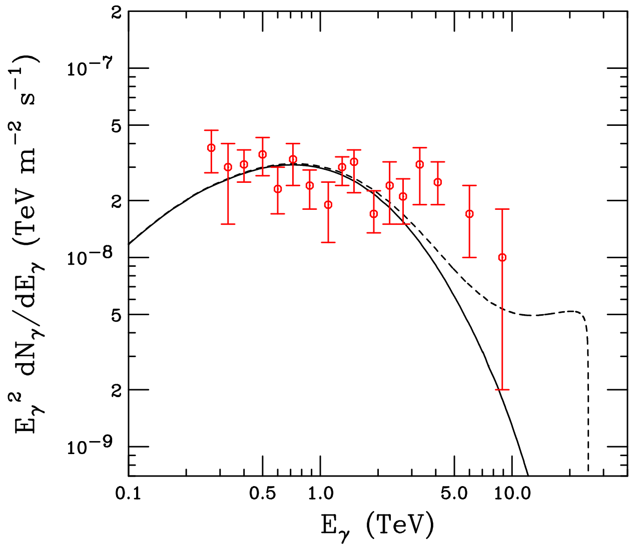
Messenger Dark Matter

- Gamma-Ray Spectrum

  -Consistent with HESS results

  -Favors 20-25 TeV mass range





Hooper and J. March-Russell, PLB, hep-ph/0412048

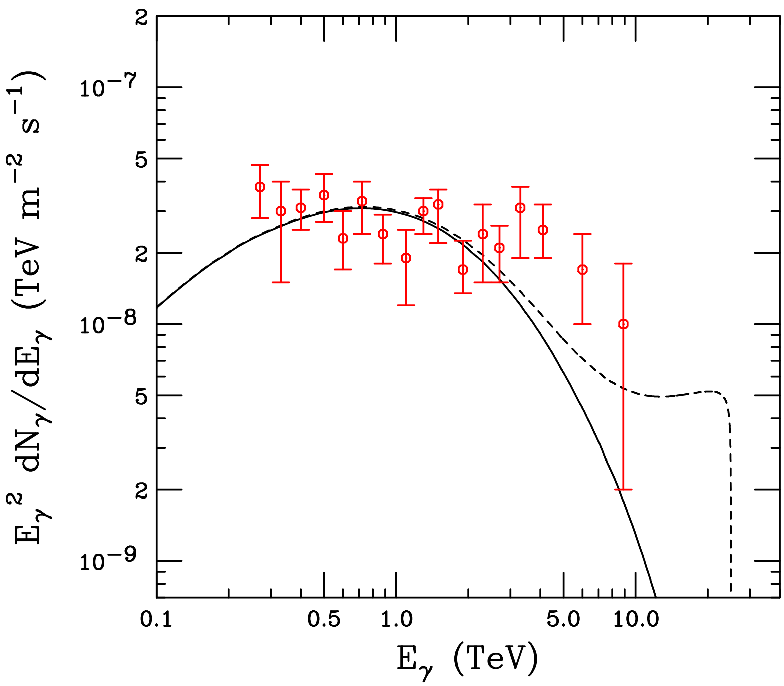
The Role of GLAST

- Gamma-Ray Spectrum

  -HESS cannot easily distinguish dark matter from power law

  -Measurements needed above 10 TeV, or below 200 GeV

  -If the product of dark matter, GLAST will see changing slope



CONCLUSIONS

- Gamma-Ray Observations of GC

  -Have ACTs Seen Signals of Annihilating Dark Matter?

  -If So, Very Heavy Particles Needed

  -Can We Accommodate These Observations With "Reasonable" Particle Physics Models?

- Messenger Dark Matter

  -Gauge Mediated SUSY Breaking Models

  -20 to 30 TeV Masses, Appropriate Cross Sections, etc.

  -Very Natural and Attractive Candidate for Dark Matter

- Many Fish In The Sea

  -MultiTeV Mass Range Has Thus Far Been Largely Ignored

  -Many Possibilities For Heavy Dark Matter Particles

  -Beyond the Reach of the Tevatron and LHC

  $\longrightarrow$ Astroparticle Physics Provides Only Hope of Discovery!